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Balancing Safety and Toxicity: A Review of Drinking Water Quality, Treatment, and Disinfection By-Products in The Philippine Context

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Abstract: *Water is a critical resource for survival, yet its quality is continually compromised by anthropogenic and natural factors. This review examines the current state of drinking water in the Philippines, specifically focusing on the Cagayan de Oro region. It explores the efficacy of standard water treatment processes—coagulation, sedimentation, filtration, and disinfection—while highlighting the "double-edged sword" of chemical disinfection. While disinfectants like chlorine are essential for eradicating waterborne pathogens, they react with natural organic matter to form potentially carcinogenic Disinfection By-products (DBPs), such as Trihalomethanes (THMs). This article synthesizes literature on physico-chemical contaminants, heavy metals, and the regulatory frameworks (PNSDW, USEPA, WHO) governing water safety, identifying a significant gap in local research regarding THM formation potential.*

Keywords: *Drinking water quality, disinfection by-products (DBPs), trihalomethanes (THMs), water treatment, chlorination*

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Introduction

Water is an extremely important resource that humans cannot live without. The two primary sources of water for public water systems are surface water and ground water (CDC, n.d.). In the Philippines, access to these resources is a critical concern. According to the 2017 Annual Poverty Indicators Survey (APIS), 94% of the 24 million Filipino families have access to improved drinking water (PSA, 2019). However, this statistic is misleading; it refers to the design of the water source rather than quality. In fact, only 34% of Filipino homes have clean drinking water free from fecal contamination at the point of usage (PSA, 2019).

The health consequences of this gap are severe. Acute watery diarrhea was one of the top ten primary causes of death in the Philippines in 2016, claiming over 139,000 lives (WHO, 2019). Furthermore, inadequate and sporadic water supply in Metro Manila and other parts of the country results in negative water pressure, which can attract contaminants and endanger water quality once supply is restored (WEPA, n.d.).

Standard Water Treatment Processes

Surface and ground water are subject to contamination and require treatment to remove disease-causing substances. Waterborne organisms such as Cryptosporidium, E. coli, Hepatitis A, Giardia intestinalis, and other pathogens can contaminate drinking water sources, causing sickness and disease.

To ensure the safety of their communities' drinking water, public drinking water systems employ a variety of water treatment processes. The most frequently employed procedures today include coagulation and flocculation, sedimentation, filtration, and disinfection (CDC, 2015).

Coagulation and Flocculation

Coagulation and flocculation are often the first steps in water treatment. Chemicals with a positive charge are added to the water. The positive charge of these chemicals neutralizes the negative charge of dirt and other dissolved particles in the water. When this occurs, the particles bind with the chemicals and form larger particles, called floc.

Sedimentation

During sedimentation, floc settles to the bottom of the water supply, due to its weight. This settling process is called sedimentation.

Filtration

Once the floc has settled to the bottom of the water supply, the clear water on top will pass through filters of varying compositions (sand, gravel, and charcoal) and pore sizes, in order to remove dissolved particles, such as dust, parasites, bacteria, viruses, and chemicals.

Disinfection

After the water has been filtered, a disinfectant (for example, chlorine, chloramine) may be added in order to kill any remaining parasites, bacteria, and viruses, and to protect the water from germs when it is piped to homes and businesses. This subject is intensively discussed in the section Water Disinfection and Disinfection Byproducts (DBPs).

Physico-Chemical Parameters

Turbidity

Turbidity is a measure of cloudiness or the relative clarity of water. It is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction through a water sample (USEPA, 1999). This is caused by suspended and colloidal matter, such as clay, silt, organic and inorganic matter, plankton, and other microorganisms.

Turbidity is used to measure the water quality and the extent to which suspended matter is removed throughout the treatment process. It has an aesthetic effect on the appearance, color, and even flavor of drinking water. It may also pose a health risk. Suspended and colloidal particles can act as food sources and shelters for pathogens. By blocking or absorbing UV radiation, turbidity can reduce the efficacy of UV disinfection (Allen, Brecher, Copes, Hrudey, & Payment, 2008). Turbidity particles provide protection for microorganisms by minimizing their exposure to disinfectants. Furthermore, if not eliminated, turbidity can stimulate pathogen regrowth in the water system, resulting in outbreaks of waterborne disease (USEPA, 1999).

Turbidity also has an effect on treatment operations, especially chemical disinfection. When chemical disinfection is utilized, turbidity with a high organic content can result in increased formation of disinfection by-products that can have long-term health consequences, particularly when higher disinfection dosages are required to provide microbially safe water (Allen, et al., 2008). Therefore, maintaining low turbidity levels is critical for successful water treatment and disinfection.

Turbidity in drinking water is typically caused by waste discharges, runoff from watersheds, algae or aquatic weeds and the products of their decomposition in water reservoirs, rivers, or lakes; humic acids and other organic compounds resulting from the decay of plants, leaves, and other organic matter in the water source; high iron concentrations that give water a rust-red color; and air bubbles and particles from treatment processes such as hydroxides and lime softening (USEPA, 1999).

The nephelometric method is the standard method in measuring turbidity. In this method turbidity is measure using an instrument called nephelometer. Nephelometer measures turbidity by determining the light scattered at angle of 90° from the incident beam. The instrument is calibrated using standardized suspension of formazin defined in Nephelometric Turbidity Units (NTU). The standard unit of turbidity is NTU.

The Philippine National Standard for Drinking Water of 2017 specified a turbidity limit of 5 NTU (DOH, 2017). The United States Environmental Protection Agency (USEPA) has established that for systems that use conventional or direct filtration, turbidity (cloudiness of water) must never exceed 1 Nephelometric Turbidity Unit (NTU), and that samples for turbidity must be less than or equal to 0.3 NTUs in at least 95% of samples taken in any month. Systems that employ filtration methods other than traditional or direct filtration must adhere to state standards, which include a turbidity limit of no more than 5 NTUs (USEPA, 2009; USEPA 2018).

Organic Matter – Total Organic Carbon and Chemical Oxygen Demand

Organic matter in water is any carbon-based substance that exists as a dissolved or particulate form. Natural organic matter is the result of a variety of breakdown and metabolic activities occurring in the water supply and its environs (CBCL Limited, 2011). They have a detrimental effect on the quality of the water (Matilainen, 2007; Texas Commision on Environmental Quality, 2002; Benjamin, Croue, & Reiber, n.d.; Payment, Waite, & Dufour, n.d.; CBCL Limited, 2011). Organic matter serves as a precursor for disinfection by products, a substrate for biogrowth, and a site for heavy metal complexation (Benjamin et al., n.d.).

Disinfection of drinking water is critical for public health protection. While disinfectants inactivate pathogens, they also react with naturally occurring organic matter to produce disinfection by-products, some of which are dangerous to human health. Numerous organic molecules react with chlorine and chloroamines to form disinfection byproducts such as trihalomethanes and haloacetic acid, which are believed to be carcinogenic and/or genotoxic (CBCL Limited, 2011; Texas Commision on Environmental Quality, 2002). Prior to disinfection, it is necessary to remove organic matter from the water system.

To remove organic matter, a variety of established and new water treatment technologies can be applied. Coagulation and flocculation are the most frequently used and economically viable methods for removing organic matter, followed by sedimentation, flotation, and sand filtration (Matilainen, 2007). Various proprietary packaged systems are also available for removing or reducing the reactivity of organic matter, such as oxidation-based systems (ozone and filtration, ozone and biological filtration, advanced oxidation process), membrane-based systems (low pressure membranes followed by coagulation, high pressure membranes working via size exclusion), and adsorption-based systems (activated carbon, resins) (CBCL Limited, 2011).

The amount of organic matter in water is determined usually by total organic carbon (TOC), dissolved organic carbon (DOC), UV absorbance, and color measurements (Matilainen, 2007; Texas Commission on Environmental Quality, 2002; CBCL Limited, 2011; Payment et al., n.d.). True and apparent color are used as rough estimates of organic matter content (CBCL Limited, 2011). Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) can also be used as measure of organic matter content (Payment et al., n.d.).

The Total Organic Carbon (TOC) test uses heat, ultraviolet light, and a strong chemical oxidant (or a combination of these three) to oxidize organic compounds to CO2 and H2O. In the method develop by Hach Company, "the total organic carbon (TOC) is determined by first sparging the sample under slightly acidic conditions to remove inorganic carbon. In the outside vial, organic carbon in the sample is digested by persulfate and acid to form carbon dioxide. During digestion, the carbon dioxide diffuses into a pH indicator reagent in the inner ampule. The absorption of carbon dioxide into the indicator forms carbonic acid. Carbonic acid changes the pH of the indicator solution which, in turn, changes the color. The amount of color change is related to the original amount of carbon present in the sample. Test results are measured at 598 and 430 nm" (Hach Company, 2014).

The chemical oxygen demand is another indicator of organic matter in water (COD). The COD is a measure of how much oxygen is required to oxidize organic matter in water. It is an important parameter in determining the extent of organic pollution in water and assessing the efficacy of treatment processes. It is commonly determined using the dichromate titration and spectroscopic methods. A dichromate ion, a strong oxidizing agent, is used in excess in both methods. As it oxidizes organic matter, the hexavalent chromium (Cr6+ or Cr(VI)) in dichromate ion is reduced to the trivalent chromium (Cr3+ or Cr(III)). In the titration method, the excess dichromate ion is back titrated with ferrous ammonium sulfate solution, whereas in the spectroscopic method, the absorbance due to excess dichromate ion is measured (Besagas & Del Rosario, 2010).

Heavy Metals

Heavy Metals in General

The term "heavy metals" has been widely used in scientific literature, particularly in studies of the environment. Although the term lacks a definitive definition in the literature, it is frequently used to refer to a group of metals and some semimetals that are associated with environmental pollution. Many definitions have been proposed; some are based on the density, atomic number, or atomic weight of the substance, while others are based on its chemical properties or toxicity. One widely used definition is based on density, with heavy metals defined as those with a density greater than 5 g/cm^3 (Järup, 2003). This definition, however, is somewhat ambiguous because it refers to the metal's elemental state. According to Appenroth (2010), this is an incorrect definition of the term when applied to plants and other living organisms. In most cases, the elemental form of metals or their alloys does not contain the reactive species with which living organisms must contend (Duffus, 2002). Moreover, plants do not deal with metals in their elemental states because they are inaccessible to them (Appenroth, 2010).

Due to the ambiguity surrounding the term "heavy metals" in the scientific literature, the term "heavy metals" is used in this research to refer to metals and semimetals in the form of compounds or salts that have been shown to be toxic or harmful to the health of humans and other living organisms. It should be noted that this study did not examine metals in their elemental state, but rather metals in the form of compounds or salts that were dissolved in the public drinking water system of Cagayan de Oro City. Metals are insoluble in water in their elemental state and must react with other elements to form compounds before they can be dissolved (Appenroth, 2010). In the present study, seven heavy metals are investigated: copper, chromium, lead, cobalt, manganese, nickel, and cadmium.

Contamination of waters with heavy metals has generated considerable concern due to the fact that it has the potential to significantly alter coastal ecosystems. Bioaccumulation of these heavy metals by marine organisms poses a threat to human health through the consumption of sea food (Huang, 2003). Consider the most severe bioaccumulation incidents in Japan. In 1953, the Minamata disease was caused by eating fish and shrimp contaminated with methyl mercury from wastewater discharged by nearby chemical manufacturing plants. In 1955, the itai-itai disease was caused by consuming rice and fish contaminated with cadmium from wastewater discharged by nearby mining activities (Chen & Chen 2001).

On the other hand, heavy metals found in nature are not harmful to the environment or human health; in fact, a number of them are required for basic body functions. They are non-biodegradable natural constituents of the Earth's crust. This is true when the amount is minimal. However, rapid industrialization, economic development, and population growth have resulted in the production of massive quantities of anthropogenic and industrial waste. These wastes are then carried downstream by rivers and dumped into the seas (Amin, Ismail, Arshad, Yap & Kamarudin, 2008). Indeed, human-caused pollution is the primary source of heavy metal contaminants in the ocean (Chen & Chen, 2001).

Cadmium

Cadmium is a heavy metal posing severe risks to human due to its serious health effects. It is one of the WHO's 10 chemicals of major public health concern along with lead (WHO, 2010).

Cadmium is naturally found in trace amounts in the environment; however, human activity has significantly increased those levels. It is naturally occurring in ores alongside zinc, lead, and copper (Järup, 2003). Cadmium is also present in coal and mineral fertilizers (Martin & Griswold, 2009). Cadmium and its compounds are widely used in industrial processes such as metal plating and coating, anticorrosive agents, stabilizers in PVC products, color pigments, neutron absorber in nuclear power plants, and nickel-cadmium battery fabrication. Cadmium-containing products are rarely recycled, but are frequently discarded with household waste, contaminating the environment, particularly when the waste is incinerated (Järup, 2003). This waste contributes significantly to cadmium exposure. Additional sources of cadmium exposure include foods and cigarettes (USEPA, 2000; Järup, 2003; Godt, Scheidig, Grosse-Siestrup, Esche, Brandenburg, Reich, & Groneberg, 2006). According to the United States Environmental Protection Agency (2000), cadmium levels in certain foods can be increased through the application of phosphate fertilizers or sewage sludge to farm fields, and smokers have approximately twice the amount of cadmium in their bodies as nonsmokers.

Excessive inhalation exposure to high levels of cadmium may cause bronchial and pulmonary irritation in humans. Acute exposure to high cadmium levels can result in long-term impairment of lung function. Consuming excessive amounts of cadmium causes severe stomach irritation, which manifests as vomiting and diarrhea. Long-term exposure to lower levels causes lung damage, bone deterioration, and a buildup in the kidneys, which may result in kidney disease (Martin & Griswold, 2009; USEPA, 2000).

Chromium

Chromium is found naturally in the earth's crust. It is found naturally in rocks, animals, plants, soil, volcanic dust, and gases. Chromium is mined as the ore chromite ($FeCr_2O_4$). Ores of chromium are currently mined in South Africa, Zimbabwe, Finland, India, Kazakhstan, and the Philippines (Sneddon, 2012). Chromium is found in metal alloys such as stainless steel, metal protective coatings (electroplating), magnetic tapes, paint pigments, cement, paper, rubber, and other materials. Its soluble forms are used in the preservation of wood (Martin & Griswold, 2009).

Chromium is found primarily in two valence states in the environment: trivalent chromium (Cr^{3+} or Cr(III)) and hexavalent chromium (Cr^{6+} Cr(VI)). Hexavalent chromium is significantly more toxic than trivalent chromium (USEPA, 2000; Martin & Griswold, 2009; Environment Agency, 2002). Humans are adversely affected by Cr(VI) exposure, and it is a suspected carcinogen (Jacobs & Test, 2004; Martin & Griswold, 2009). In humans, chronic inhalation exposure to chromium (VI) causes effects on the respiratory tract, including septum perforations and ulcerations, bronchitis, decreased pulmonary function, pneumonia, asthma, nasal itching and soreness, and damage to the liver, kidney, gastrointestinal, and immune systems, as well as possibly the blood (USEPA, 2000). By inhalation, the USEPA has classified chromium (VI) as a Group A, known human carcinogen. Chromium (III), on the other hand, is a mineral that is essential for glucose and fat metabolism. The biologically active form of an organic Cr(III) complex is thought to work by facilitating insulin's interaction with its cellular receptor sites. Chromium supplementation improves glucose, protein, and lipid metabolism in deficient and marginally deficient subjects, according to studies (Jacobs & Test, 2004). Despite being an essential nutrient and far less toxic than Cr(VI), acute animal tests have revealed that chromium (III) has moderate toxicity from oral exposure (USEPA, 2000).

Copper

Copper occurs naturally as a free metal or in combinations with other elements that make up a variety of minerals. It is frequently encountered in nature in conjunction with sulfur (USGS, 2014). Copper is one of the oldest metals known to mankind. It has played a significant role in the evolution of civilization and will continue to do so in the future. Copper ranks third in terms of consumption after iron and aluminum as key industrial metals (USGS, 2014). Copper is a useful metal due to its chemical and physical qualities, which include high heat conductivity, high electrical conductivity and malleability, resistance to corrosion, alloyability, and an aesthetically pleasant look.

Copper is a component of many metalloenzymes and respiratory pigments, and it is considered an essential trace element for plants and animals. It's needed to make chlorophyll (a photosynthetic pigment found in plants) and hemoglobin (a respiratory blood pigment). Hemocyanin, the respiratory blood pigment found in many mollusks and other invertebrates, uses copper as an oxygen coupling site.

Copper is necessary for plant metabolism to function properly. Reduced production of the copper-containing electron carriers plastocyanin and cytochrome oxidase is caused by copper deficiency. Photosynthesis and respiration are slowed when these electron carriers are depleted. When biological requirements are surpassed, copper becomes hazardous, especially to aquatic life (Alberta Environmental Protection, 2006).

The majority of copper compounds have valence states of +1 (monovalent, Cu(I)) or +2 (divalent, Cu(II)). The main toxic form of copper is cupric ion (Cu(II)) (Alberta Environmental Protection, 2006). Excessive copper exposure can cause liver and kidney damage, anemia, immunotoxicity, and developmental toxicity, among other things. Many of these effects are consistent with membrane or macromolecular oxidative damage. Copper can bind to the sulfhydryl groups of various enzymes, including glucose-6-phosphatase and glutathione reductase, impairing their ability to protect cells from free radical damage.

Lead

Lead is present in every aspect of our surroundings. Much of it is produced by human activities such as fossil fuel combustion, mining, and manufacturing. Lead has a wide variety of applications. It is used to make batteries, ammunition, metal products (solder and pipes), and X-ray shielding devices. Lead levels in gasoline, paints and ceramic products, caulking, and pipe solder have been significantly lowered in recent years due to health concerns (ATSDR, 2011). It is harmful to the majority of life forms at high concentrations (Goyer & Clarkson, 1991).

For the general population, the primary route of exposure is through food, and the sources of excess exposure and harmful effects are typically environmental and apparently controlled. These sources include lead-based interior paint in older dwellings, lead in dust from environmental sources, lead in contaminated drinking water, lead in the air from industrial emissions containing lead, hand-to-mouth activities of young children living in polluted environments, lead-glazed pottery, and lead dust brought home by industrial workers on their shoes and clothing (Järup, 2003; Goyer & Clarkson, 1991). Lead poisoning can cause severe damage to the brain and kidneys and eventually death. Lead exposure at high levels during pregnancy may result in miscarriage. In men, prolonged exposure can wreak havoc on the organs responsible for sperm production (Martin & Griswold, 2009).

Nickel

Nickel occurs naturally in combination with other elements in the earth's crust. It is present in every type of soil and is also emitted by volcanoes. It is most frequently found in the environment in combination with oxygen or sulfur as oxides or sulfides (ATSDR, 2005). Nickel is the twenty-fourth most abundant element on earth.

Nickel typically possesses two valence electrons, although it can also exist in the oxidation states +1, +3, or +4. Metallic nickel is impervious to water but is slowly attacked by dilute hydrochloric or sulfuric acids and is easily attacked by nitric acid. Nickel is not affected by fused alkali hydroxides. Numerous nickel salts, including acetate, chloride, nitrate, and sulfate, are soluble in water, although carbonates and hydroxides are much less so, and sulfides, disulfides, subsulfides, and oxides are essentially insoluble (WHO, 2005).

Nickel is primarily used to manufacture stainless steels, nonferrous alloys, and superalloys. Nickel and nickel salts are also used in electroplating, as catalysts, nickel–cadmium batteries, coinage, welding products, and some pigments and electronic components.

Nickel absorption is proportional to its physicochemical state, with water soluble forms being more readily absorbed. Nickel undergoes a number of chemical transformations and is bound to a variety of ligands during its metabolism (ATSDR, 2005). Nickel is eliminated in the urine and feces in different proportions depending on the route of exposure and chemical type. Although the majority of nickel enters the body through food and water consumption, occupational exposure is the principal route of nickel-induced toxicity (WHO, 2005).

Acute inhalation exposure to nickel can cause headaches, nausea, respiratory problems, and mortality in humans. Asthmatic symptoms have also been reported following nickel inhalation exposure. Nickel compounds that are soluble in water are often more hazardous than those that are insoluble in water. Additionally, nickel carbonyl is known to be exceedingly hazardous to humans when inhaled in high concentrations (Goyer & Clarkson, 2001). Oral exposure to nickel has been shown to have toxic effects on the kidneys, with some evidence from animal research indicating a possible developmental/reproductive toxicity effect (ATSDR, 2005). The lungs and upper respiratory tract are the principal organs affected by nickel-induced systemic toxicity following inhalation exposure, while the kidneys are the primary organ affected following oral exposure (ATSDR, 2005). Additionally, the cardiovascular system, immunological system, and blood are also target organs.

Cobalt

Cobalt is a naturally occurring element that is similar to nickel and iron in its characteristics. Cobalt exists in a variety of isotopes, all of which are unstable and radioactive except for cobalt-59, which is the only stable isotope. Cobalt is an element that is typically found in combination with other elements such as arsenic, oxygen, and sulfur. In trace amounts, these chemical compounds are found in rocks, soil, plants, and animals. Cobalt is present in water as a dissolved or ionic species, usually in trace levels (ASTRDR, 2004). In seawater, surface water, spring water, and groundwater, cobalt compounds have been discovered to occur naturally (Smith & Carson, 1981).

Exposure to amounts of cobalt prevalent in the environment is not dangerous to humans or animals. Human health is affected by cobalt in both positive and negative ways. Cobalt is found in most tissues because it is a component of vitamin B12, which is necessary for human health. The total body burden is expected to be between 1.1 and 1.5 milligrams, including 0.11 milligrams in the liver (Kim et al., 2006). Because cobalt causes the production of red blood cells, it is administered to pregnant women and used to treat anemia at a dose of 0.16-1.0 mg cobalt/kg body weight (ASTDR, 2004). Cobalt is also necessary for the health of a variety of animals, including sheep and cattle.

However, when an excessive amount of cobalt is ingested, adverse health effects might ensue. Workers who inhaled air with 0.038 mg cobalt/m^3 (about 100,000 times the concentration present in ambient air) for six hours had difficulty breathing. Serious pulmonary effects, such as asthma, pneumonia, and wheeze, have been observed in individuals exposed to 0.005 mg cobalt/m^3 while working with hard metal, a cobalt-tungsten carbide alloy. Workers exposed to 0.007 mg cobalt/m^3 experienced cobalt allergies, resulting in asthma and skin rashes (Kim et al., 2006).

Manganese

Manganese is one of the most common metals found in the Earth's crust, and it frequently occurs in conjunction with iron. It's present in over 100 minerals, but it's not found in its pure (elemental) form in nature (ATSDR, 2000). Manganese is required for the normal functioning of several cellular enzymes (e.g. manganese superoxide dismutase, pyruvate carboxylase) and can help to activate others (e.g. kinases, decarboxylases, transferases, hydrolases) (IPCS, 2002). Manganese can exist in 11 different oxidative states, with Mn^{2+}, Mn^{4+}, and Mn^{7+} being the most environmentally and biologically important (USEPA, 1994).

Manganese compounds can be found in the atmosphere as suspended particles as a result of industrial emissions, soil erosion, volcanic emissions, and the combustion of MMT (methylcyclopentadienyl manganese tricarbonyl)-containing petrol (IPCS, 1999). Manganese can be found in both dissolved and suspended forms in surface waters, depending on pH, anions present, and oxidation–reduction potential (ATSDR, 2000). Dissolved manganese levels in anaerobic groundwater are frequently high. At pH 4–7, the divalent form (Mn^{2+}) predominates in most water, although higher pH values or microbial oxidation might result in more highly oxidized forms (ATSDR, 2000). Manganese can be adsorbed onto soil, with the amount of adsorption determined by the soil's organic content and cation exchange capacity. It can bioaccumulate in lower organisms (for example, phytoplankton, algae, mollusks, and some fish), but not in higher organisms; biomagnification in food chains is unlikely to be substantial (ATSDR, 2000).

Manganese is not typically thought to be highly hazardous when consumed in food due to the homeostatic control that humans have over manganese. Manganese intakes for adults in typical Western and vegetarian diets ranged from 0.7 to 10.9 mg/day (Greger, 1999; IOM, 2002). Manganese consumption values in the upper range of 11 mg/day from dietary studies are regarded to have no-observed-adverse-effect-level (NOAEL). This level of manganese in the diet is not considered to be excessive (IOM, 2002). Exposure to extremely high levels of manganese dust or fumes, on the other hand, results in irreversible adverse neurological effects such as weakness, anorexia, muscle pain, apathy, slow speech, monotonous tone of voice, emotionless "mask-like" facial expression, and slow, clumsy movement of the limbs (Canavan et al., 1934; Cook et al., 1974; Roels et al., 1992; ATSDR, 2000).

Manganese in drinking water can be an issue for customers if the manganese is deposited in water mains and causes water coloring. However, this may vary depending on local conditions. Concentrations below 0.05 mg/l are generally acceptable to consumers (WHO, 2011).

Coliform Bacteria – Total Coliform and *Escherichia Coli*

The coliform test is one of the most critical tests for determining the quality of drinking water. Coliforms are a category of bacteria that are frequently found in the environment, most notably in soil and the intestines of humans and other warm-blooded animals. Coliforms are categorized into two types: total coliforms and fecal coliforms. The term "total coliform" refers to all coliform bacteria, whereas the term "fecal coliform" refers to a subset of the total coliform group that often originates in the intestines of humans and animals and is thus found in human and animal feces. *E. coli*, is a prominent fecal coliform species.

While total coliform and E. coli are generally regarded non-pathogenic organisms, their presence indicates the existence of other pathogenic species such as bacteria, viruses, and protozoa. However, certain strains of *E. coli*, most notably *E. coli* O157:H7, are capable of causing sickness. *E. coli* O157:H7 infection can cause severe diarrhea and a potentially fatal complication termed hemolytic uremic syndrome, in which red blood cells are damaged and the kidneys fail (USEPA, 2013). Hemolytic uremic syndrome is the leading cause of acute kidney failure in children in the United States, and the majority of cases are caused by *E. coli* O157:H7 (USEPA, 2013). Cattle, chickens, pigs, and sheep have all been discovered to have *E. coli* O157:H7 (New York State DOH, 2011).

Water used for drinking is frequently contaminated with coliforms and pathogens. Contamination of drinking water with pathogenic organisms is mostly caused by agricultural runoff, storm water runoff, inadequately treated septic and sewage discharges, and infiltration of domestic or wild animal feces (Brunswick, n.d.; British Columbia Ground Water Association, 2007). However, tests to detect individual viruses in drinking water are rarely conducted since they are not only time consuming, sophisticated, and expensive, but also practically impossible. Rather of that, total coliform and *E. coli* tests are performed. Although they are normally nonpathogenic, total coliforms and *E. coli* are indicator species for pathogens, and positive test results indicate the presence of disease-causing organisms. Additionally, positive results for total coliform and *E. coli* should be interpreted as an indicator of fecal pollution in the water system.

The Philippine Department of Health requires that drinking water have a total coliform count of less than 1 colony forming unit (cfu) per 100 mL sample and be free of *E. coli* (DOH, 2017). In the United States, the Environmental Protection Agency (USEPA) requires that no more than 5.0 percent of routine samples be total coliform-positive in a month, and no more than one sample be total coliform-positive in a month for water systems that collect fewer than 40 routine samples per month. Each sample containing total coliforms must be tested for fecal coliform or *E. coli*. If two consecutive total coliform positive tests are also positive for E. coli or fecal coliforms, the system is in acute violation of the MCL (maximum contamination level) (USEPA, 2009). Chlorine, UV light, ozone, or distillation can be used to treat microbially contaminated water systems.

Water Disinfection and Disinfection Byproducts (Dbps)

Disinfection is a process that is routinely performed during the water treatment process in order to render pathogenic microorganisms inactive and so prevent microbiological degradation of the drinking water's quality. The disinfection process is divided into two stages: primary disinfection and secondary disinfection. Water is disinfected prior to use in primary disinfection to achieve the appropriate level of microbial death or inactivation. On the other side, secondary disinfection assures the presence of residual disinfectants throughout the distribution process, which helps keep the water microbiologically safe by inhibiting microbe regrowth.

Disinfection has been critical in the global effort to eradicate waterborne diseases such as cholera and typhoid fever. As such, disinfection is a critical component of public health. The following Table 1 summarizes the primary diseases spread via drinking water.

Table 1. Major Waterborne Diseases Transmitted via Drinking Water (Maier et al., 2000)

Group	Pathogen	Disease or Condition
Viruses	Enteroviruses (polio, echo, coxsackie)	Meningitis paralysis, fever, diarrhea
	Hepatitis A & E	Hepatitis
	Norwalk virus	Diarrhea
Bacteria	*Salmonella*	Typhoid, diarrhea
	Shigella	Diarrhea
	Campylobacter	Diarrhea
	Vibrio cholerae	Diarrhea
	Escherichia coli	Diarrhea
	Legionella	Pneumonia
Protozoa	*Giardia lamblia*	Diarrhea
	Cryptosporidium	Diarrhea
Blue-green algae	*Anabaena* *Microcystis*	Diarrhea, possible productions of carcinogens
Helminths	*Necuter americanus*	Hookworm
	Taenia saginata	Tapewrom

Chlorine, chloramines, chlorine dioxide, ozone, and UV radiation are all commonly used disinfectants (Durmishi et al., 2015). Disinfectants work in a variety of ways, including damaging pathogen cells, altering cell wall permeability, and reacting with pathogen enzymes (Cabral, 2010). The qualities of the water to be treated influence the design of an appropriate water treatment system. The water supply, turbidity, color, pathogen level, and hardness are all factors in disinfection (Safferman, 2010).

Chlorine

The most prevalent disinfectants for drinking water are chlorine and its derivatives. It is not only effective in eradicating infections, but it is also cost-effective to utilize. In addition, chlorine has a higher oxidation potential, allowing for a low residual disinfectant level in the distribution system while preventing microbiological recontamination (Sadiq et al., 2004). Hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) are formed when chlorine combines with water (equation 1 and equation 2). The pH of this reaction is important. Because hypochlorous acid is a more powerful disinfectant than hypochlorite ion, disinfection with chlorine requires a lower pH (Durmishi et al., 2015). By targeting the bacterial cell and the viral protein, chlorine (HOCl or OCl-) kills bacteria and viruses.

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^- \quad (1)$$
$$HOCl \rightleftharpoons OCl^- + H^+ \quad (2)$$

While chlorine reduces the risk of pathogenic infection, it may pose a different kind of threat to human due to the formation of harmful byproducts. Chlorination produces disinfection byproducts (DBP) only if the water contains a DBP precursor (Achour & Chabbi, 2014). Organic molecules such as humic and fulvic acid may be transformed into potentially dangerous byproducts such as trihalomethanes (THMs), haloacetic acids (HAAs), chlorophenols, chloral hydrate, and haloacetonitriles (HANs) during chlorination (Achour & Chabbi, 2014; Hrudey, 2009). The reaction between chlorine and organic materials in general can be represented as follows (equation 3) (Fooladvand, Ramavandi, Zandi, & Ardestani, 2011):

$$\text{organic matter} + \text{free chlorine} \longrightarrow \text{THMs} + \text{HAAs} + \text{HANs} + \text{cyanogen halides} + other\ DBPs \quad (3)$$

Chloramines

Chloramines are an alternative to chlorine as a water disinfectant. Unlike chlorine, which has an effect on the odor and taste of drinking water, chloramines have no such effect. Moreover, chloramines are an excellent secondary disinfectant because they are more stable than free chlorine in the distribution system (Durmishi et al., 2015). In other words, chloramines are more effective in inhibiting bacterial growth during distribution than other disinfectants. Additionally, chloramine disinfection produces lower levels of DBPs, particularly trihalomethanes, than chlorination. It does, however, yield additional byproducts such as cyanogen chloride. Chloramination is the process of adding ammonia and chlorine to water. Monochloramine (NH_2Cl), dichloramine ($NHCl_2$), or trichloramine (NCl_3) are formed when ammonia combines with chlorine. Their formation is illustrated by the following equations (4, 5, and 6):

$$NH_4^+ + HOCl \rightleftharpoons NH_2Cl + H_2O + H^+ \quad (4)$$
$$NH_4^+ + HOCl \rightleftharpoons NHCl_2 + H_20 \quad (5)$$
$$NHCl_2 + HOCl \rightleftharpoons NCl_3 + H_2O \quad (6)$$

Chlorine Dioxide

Although chlorine dioxide is a more powerful oxidant than chlorine, it is more expensive to utilize in water treatment. It is an unstable and highly volatile gas that must be generated on-site (Latifoglu, 2003). It quickly degrades to chlorites and chlorates. Because it does not produce chlorinated organic byproducts, particularly trihalomethanes, chlorine dioxide is a better disinfectant for drinking water than chlorine (Durmishi et al., 2015; Gallard and von Gunten, 2002). Chlorine dioxide's byproducts are primarily carboxylic acids, notably malaec acids (Richardson et al., 1994).

In the presence of iron and manganese, chlorine dioxide is converted to chlorates, whereas at high pH (pH > 10) it rapidly hydrolyzes and forms chlorites and chlorates (equation 7). Chlorites are reasonably stable in the presence of natural organic matter (NOM), but if chlorine is introduced as a secondary disinfectant, they can oxidize to ClO_3^- from free Cl_2 (Durmishi et al., 2015). Chlorates and chlorites are considered as inorganic disinfection by products. ClO_3^- and ClO_2^- are both inorganic byproducts that can cause hemolytic anemia in low doses and methemoglobinemia in large concentrations (Corn and Graubard, 2002). Thus, the drawback of employing ClO_2 over Cl_2 is the health risk posed by residual oxidizers, in addition to the high operating expenses.

$$2ClO_2 + 2OH^- \rightleftharpoons ClO_2^- + ClO_3^- + H_2O \quad (7)$$

Ozone

Ozone is a highly effective disinfectant that is well suited for primary disinfection of water and sewage treatment plants (Durmishi et al., 2015). However, because ozone leaves no stable chemical residue, it is not ideal for secondary disinfection (USEPA, 1999). Ozone produces HO_2• and HO• free radicals when it combines with water (equation 8, 9, 10, and 11). These free radicals are the disinfection process's active chemicals. Free radicals are capable of neutralizing viruses and damaging bacteria's cell walls. Ozone is a more effective disinfectant and virucidal agent than chlorine (WCC, 2008; USEPA, 2011).

$$O_3 + H_2O \rightleftharpoons H_3^+ + \cdot OH^- \quad (8)$$
$$HO_3^- + \cdot OH^- \rightleftharpoons 2HO_2 \cdot \quad (9)$$

$$O_3 + HO_2 \cdot \rightleftharpoons HO \cdot + 2O_2 \quad (10)$$
$$HO \cdot + HO_2 \cdot \rightleftharpoons H_2O + O_2 \quad (11)$$

Depending on the dose and contact time, the use of ozone during primary disinfection minimizes the likelihood for THM production. For samples from the coagulation, sedimentation, and filtration processes in a water treatment facility, the possibility for THM generation is reduced by 32% with an ozone dosage of 227 mg/L and a contact time of 5 to 6 minutes (Trussell and Umphres, 1978). According to studies, ozone degrades humic compounds into less reactive molecules toward chlorine (Amy et al., 1991; Corn and Graubard, 2002). When bromides are disinfected with ozone, bromates and formic aldehyde are produced. Additionally, halopropanones and chlorinated hydrates are generated as a result of ozone disinfection (Durmishi et al., 2015).

Ultraviolet Radiation

Ultraviolet light is occasionally used to sterilize water. UV radiation inhibits pathogen growth by destroying the DNA or RNA of the organisms as it penetrates the cell wall. The advantage of UV light is that it produces extremely low levels of byproducts (Durmishi et al., 2015). However, high turbidity and high mineral concentrations in water reduce the effectiveness of UV disinfection. Furthermore, because this type of disinfection does not generate residual disinfectant, it can be used solely as a primary disinfectant. When UV light is used as the primary disinfection, chlorine gas must be added as a secondary disinfectant (Durmishi et al., 2015).

Trihalomethanes (THM)

The Formation of THM

Trihalomethanes are organic molecules having a structure identical to methane, but with three hydrogen atoms replaced by halogens. THM are technically halogenated methane. These chemicals were identified in 1974 as byproducts of chlorination of drinking water in the Netherlands by Rook, J.J., and in the United States of America by Bellar et al (Durmishi et al., 2015; Lu, Chung, & Chang, 2005). They are generated when the disinfectant chlorine combines with organic materials found in source water, particularly surface water, such as humic acids (Carpi & Zufall, 2003). Chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$), and bromoform ($CHBr_3$) are the most often observed trihalomethanes in disinfected water (Ivahnenko & Barbash, 2004; Carpi & Zufall, 2003). All four of these compounds are together referred to as total trihalomethanes (TTHM). Trihalomethanes are classified as a chemical that is potentially hazardous and carcinogenic (Bull et al., 1995).

Both the humic and fulvic fractions of organic materials have been shown to be significant precursors of THM (Fooladvand et al., 2011; Christman et al., 1990). Humic compounds, which account for between 30% and 50% of the total dissolved organic carbon in natural water, have been identified as the primary THM precursor in drinking water (Pelizetti et al., 1994; Rook, 1976; Rook, 1977; Stevens, 1976). A study demonstrated that throughout the full reaction time, the THM production kinetics can be predicted using a second-order kinetic model, first order in reactive chemicals, and first order in chlorine (Clark, 1998). The simulated long-term generation of THM in the solution containing extracted humic material exhibits good linearity when the second-order model is used and the rate constant is between 0.01 and 0.03 $M^{-1}s^{-1}$ for surface waters with a pH range of 7-9. While ground water has a greater rate constant of 0.124 $M^{-1}s^{-1}$ (Gallard & von Gunten, 2002).

Factors Affecting THM Formation

Trihalomethane formation in water is dependent on various elements, including chlorine type and dosage, humic substances type, total organic carbon concentration, pH, temperature, contact time, water flow routes, system operating conditions, and procedures for maintaining a residual disinfectant (Latifoglu, 2003; Durmishi et al., 2015). The elevated values of these parameters all support an increase in trihalomethane concentrations. For instance, in the case of TOC, it is expected that when the level of free chlorine in the water grows, the THM concentration will increase proportionately. Simpson and Hayes (1998) investigated the relationship between THM production and TOC levels by chlorinating various sources of raw water with high TOC levels. At TOC values of 11.3 mg/L (the highest concentration), they measured a THM content of 189 μg/L.

Previous research indicated that the production of THM increases with increasing pH levels (Rook, 1976; Stevens, 1976). This is because the production of THM is a halogenation reaction catalyzed by a base (Latifoglu, 2003). Temperature's effective catalytic activity is also expected to increase the rate of the reaction. For instance, THM concentrations were found to be greater in samples taken following chlorination at elevated temperatures (Abd El-Shafy and Grünwald, 2000). Another aspect affecting the formation is the amount of chlorine used. At high chlorine concentrations, oxidative degradation rather than substitution occurs, resulting in an increase in THM production (Johnson and Jensen, 1986).

Health Risks of THM

Trihalomethanes were classified as primary pollutants by the USEPA due to their tumorigenic properties and harmful effects on the nervous system, as demonstrated in animal experiments (Walter and Tassos, 1997). Chloroform is classed as a potential human carcinogen by all routes of exposure based on evidence that it causes cancer in animals. Chloroform at a high concentration may result in the production of regenerative nodules or cytotoxicity in vulnerable tissues (USEPA, 2002). Chronic THM consumption has been linked to kidney, liver, and intestine tumorigeneses in animals (Dunnick and Melnick, 1993; Doyle et al., 1997). The toxicological effects of THMs from various animal studies are summarized in Table 2.

Table 2. Toxicological Effects of THMs on Animals

Compound	Toxicological Effects
$CHCl_3$	• Liver tumors in male rats[1] • Liver tumors in mice (male and female)[1] • Act as tumor-genesis in the cytotoxicity in liver and kidney[2]
$CHCl_2Br$	• Tumors in the intestines and kidneys in mice (both male and female)[3] • Liver tumors in male mice[3] • Increases the weight of the liver in mice[4] • Causes hypomethylation of the DNA (on female mice)[4] • Increase of the weight of the liver, enhanced cell proliferation and c-myc hypomethylation[4] • Causes abnormal crypt-foci (male mice)[4]
$CHBr_3$	• Causes tumors in the intestines, polyps adenomatous and adencocarcinomas amongst mice.[5]
Other Br THMs	• Causes abnormal crypt-foci (male mice)[4]

[1]International Agency for Research on Cancer, IARC (1999) [4]Coffin, et al., (2000) [2] Komulainen (2004) [5]De Angelo (2002) [3]George, et al., (2002)

Epidemiological studies have discovered that individuals exposed to chlorination byproducts have an increased risk of developing brain, bladder, and colon-rectum cancers (Hsu, Jeng, Chang, Chien, & Han, 2001). Furthermore, trihalomethanes have been linked to miscarriage, birth abnormalities, fetal development retardation, and kidney and liver damage (Wright et al. 2004; Ristoiu et al. 2009). The following Table 3 outlines the toxicological effects of THMs on humans.

Individuals are exposed to THMs and other volatile chemicals in tap water in three ways: through ingestion, through inhalation, and through skin absorption.

Traditional risk evaluations for water frequently focus exclusively on ingesting exposure to harmful chemicals, despite the fact that showering has been found to raise the body burden of certain chemicals through inhalation and skin absorption. In southern Taiwan, exposure to THMs via food was 47.9 μg/day, whereas exposure via inhalation as a result of showering was 30.7 μg/day (Lin and Hoang, 2000).

Table 3. Toxicological Effects of THMs on Humans

DBP	Compound	Classification	Toxicological Effects
THMs	$CHCl_3$	Possible human carcinogen (with some epidemiological evidence)	Cancer, liver, kidney and reproductive effects
	$CHClBr_2$	Possible human carcinogen	Nervous system, liver, kidney and reproductive effects
	$CHCl_2Br$	Possible human carcinogen (with some epidemiological evidence)	Cancer, liver, kidney and reproductive effects
	$CHBr_3$	Possible human carcinogen (with some epidemiological evidence)	Cancer, liver, kidney and reproductive effects

Source: Alternative Disinfectants and Oxidants Guidance Manual, United States Environmental Protection Agency (USEPA, 1999)

Strategies of Controlling THMs

There are three fundamental ways for regulating trihalomethane concentrations in water (Durmishi et al., 2015; Latifoglu, 2003):

1. elimination of humic substances and other precursor chemicals;
2. elimination of the generated THM; and/or

3. reduction or prevention of THM generation by the use of alternative disinfectants.

Adsorption, filtering, coagulation, and chemical oxidation can all be used to remove the THM precursor. Adsorption, filtration, and coagulation simply transfer THM precursor from aqueous to solid phase. The elimination of precursor utilizing coagulation, sedimentation, and subsequently filtration procedures resulted in a reduction of up to 50% to 60% in THM content (Latifoglu, 2003). THM precursors can also be removed from water using a variety of chemical oxidants. According to scientific studies, ozone is effective at degrading THM precursors, particularly humic chemicals, into low molecular weight molecules that are less reactive to chlorine (Amy et al., 1991; Graham et al., 1994). Advanced oxidation methods, such as ozone in the presence of UV radiation or hydrogen peroxide, are usually more successful than utilizing simply one oxidant (Glaze et al., 1982; Duguet et al., 1985). Humic materials can also be destroyed by hydrogen peroxide in the presence of UV radiation, lowering the possibility for THM production (Gen-Shuh et al., 2000; Akata and Gurol, 1992).

THMs can be eliminated from drinking water using activated carbon or air bubbles. Chloramines, chlorine dioxide, relocating chlorination stations, and the use of powdered activated carbon are only a few of the technologies used to manage trihalomethanes in accordance with the US National Intern Primary Drinking Water Standards (Durmishi et al., 2015). Because THM are highly volatile compounds, users can also reduce the amount of THM in their tap water by boiling it. According to a study, boiling water significantly reduces the THM levels by 61–82 percent (Kuo et al., 1997).

Alternative disinfectants may be used if they meet the THMs limit and maintain residual disinfectant in the distribution system. Switching from chlorine to chloramine might be an effective strategy (Durmishi et al., 2015).

Levels of THMs in Drinking Water in the Philippines

No scientific studies or papers have been published regarding the presence of trihalomethanes in Philippine drinking water.

Quality Guidelines and Regulatory Standards For Drinking Water

Safe and readily available water is vital for public health, whether it is used for drinking, domestic use, food production, or recreation. The purpose of providing safe drinking water is to decrease human exposure to chemical and physical hazards that can be ingested through polluted water, in addition to eliminating waterborne infections. As a result, in order to protect public health, national and municipal officials, as well as administrators of public water systems, must adhere to strict legislation and regularly monitor water supply systems. Regulations and continuous water supply system monitoring are required to preserve public health. Some of the most essential physicochemical characteristics of water quality include pH, alkalinity, salinity, conductivity, total dissolved solids (TDS), total suspended solids (TSS), turbidity, and total organic carbon (TOC).

The Department of Health (DOH) in the Philippines is responsible for establishing drinking water standards that determine threshold limits for certain pollutants detected in drinking water. The Code on Sanitation of the Philippines, Chapter II (Water Supply), Section 9 states that "Standards for drinking water and their microbiological and chemical examinations, together with the evaluation of results, shall conform to the criteria set by the National Drinking Water Standards". The standard limits are meant to manage the risk associated with risks that could jeopardize the safety of drinking water, hence avoiding adverse health consequences associated with lifelong exposure to contaminants via water intake.

Because the nature and form of drinking-water standards differ between countries and regions, there is no single strategy that is generally applicable (WHO, 2017). As a result, the study will compare the water quality of Cagayan de Oro's raw and processed drinking water supplies to World Health Organization (WHO) drinking water guidelines, USEPA Drinking Water Standards, and the Philippine National Standards for Drinking Water of 2017 (DOH, 2017; USEPA, 2018; WHO, 2017).

The following tables summarize the standard values for several important water quality parameters established by the PNSDW, the USEPA, and the WHO. The Table 4 contains standards for microbiological aspects, the Table 5 contains standards for acceptability in terms of selected physical and chemical characteristics, the Table 6 contains standard values for chemicals used in treatment and disinfection, as well as disinfection by-products, and the Table 7 contains standards for inorganic contaminants, including heavy metals.

Table 4. Standard Values for Microbiological Quality of Drinking-Water.

Parameter	Standard Values / Maximum Allowable Level (MAL) / Maximum Contaminant Level (MCL)		
	PNSDW	USEPA	WHO
Total Coliforms	< 1 total coliform colonies /100 mL	5 % (No more than 5.0% samples total coliform positive in a month. Every sample that has total coliforms must be analyze for fecal coliforms no fecal coliforms are allowed.)	
Thermotolerant Coliform/*E.coli*	< 1 thermotolerant coliform colonies /100 mL	zero	Must not be detectable in any 100 mL sample
Heterotrophic Plate Count	< 500 CFU/mL		
Turbidity	5 NTU	< 5 NTU	< 5 NTU

Table 5. Standard Values for Physical and Chemical Quality for Acceptability Aspects of Drinking-Water.

Parameter	Standard Values / Maximum Allowable Level (MAL) / Maximum Contaminant Level (MCL)		
	PNSDW	USEPA	WHO
Taste	No objectionable taste		

Parameter	Standard Values / Maximum Allowable Level (MAL) / Maximum Contaminant Level (MCL)		
	PNSDW	USEPA	WHO
Odor	No objectionable odor	3 threshold odor numbers	No health-based guideline value is proposed
Color	10 CU	15 (color units)	No health-based guideline value is proposed
pH	6.5 – 8.5	6.5 – 8.5	Not of health concern at levels found in drinking water
Total Hardness	300 mg/L		Not of health concern at levels found in drinking water
Total Dissolved Solids	600 mg/L	500 mg/L	No health-based guideline value is proposed
Copper (Cu)	1.0 mg/L	1.0 mg/L	2.0 mg/L
Iron (Fe)	1.0 mg/L	0.3 mg/L	Not of health concern at levels found in drinking water
Sodium (Na)	200 mg/L		Not of health concern at levels found in drinking water
Zinc (Zn)	5.0 mg/L	5 mg/L	Not of health concern at levels found in drinking water

Table 6. Standard Values for Chemicals Used in Treatment and Disinfection and Disinfection By-products of Drinking Water.

Parameter	Standard Values / Maximum Allowable Level (MAL) / Maximum Contaminant Level (MCL)		
	PNSDW	USEPA	WHO
Chlorine Residual (as Free Chlorine)	0.3 mg/L – 1.5 mg/L	4.0 mg/L	5.0 mg/L
Bromoform	0.1 mg/L	0.08 mg/L	0.1 mg/L
Bromodichloromethane (BDCM)	0.06 mg/L	0.08 mg/L	0.06 mg/L
Chloroform	0.3 mg/L	0.08 mg/L	0.3 mg/L
Dibromochloromethane (DBCM)	0.1 mg/L	0.08 mg/L	0.1 mg/L
Total Trihalomethane (THM)	1 mg/L	0.08 mg/L	The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1

Table 7. Standard Values for Inorganic Chemical Parameters of Drinking Water.

Parameter	Standard Values / Maximum Allowable Level (MAL) / Maximum Contaminant Level (MCL)		
	PNSDW	USEPA	WHO
Antimony (Sb)	0.02 mg/L	0.006 mg/L	0.02 mg/L
Arsenic (As)	0.01 mg/L	0.010 mg/L	0.01 mg/L
Barium (Ba)	0.70 mg/L	2 mg/L	0.7 mg/L
Boron (B)	2.00 mg/L		2.4 mg/L
Cadmium (Cd)	0.003 mg/L	0.005 mg/L	0.003 mg/L
Chromium, Total (Cr)	0.05 mg/L	0.1 mg/L	0.05 mg/L
Cyanide, Total (CN^-)	0.50 mg/L	0.2 mg/L	

Parameter	Standard Values / Maximum Allowable Level (MAL) / Maximum Contaminant Level (MCL)		
	PNSDW	USEPA	WHO
Fluoride (F^-)	1.50 mg/L	4 mg/L	1.5 mg/L
Lead (Pb)	0.01 mg/L	0.015 mg/L	0.01 mg/L
Manganese (Mn)	0.4 mg/L		Not of health concern at levels causing acceptability problems in drinking-water
Mercury, Total (Hg)	0.001 mg/L	0.002 mg/L	0.006 mg/L
Nickel (Ni)	0.07 mg/L		0.07 mg/L
Nitrate (NO_3^-)	50.00 mg/L	10 mg/L	50 mg/L
Nitrite (NO_2^-)	3.00 mg/L	1 mg/L	3 mg/L
Selenium (Se)	0.04 mg/L	0.05 mg/L	0.04 mg/L

Local Context and Research Gaps

Research on the 28 freshwater sources in Misamis Oriental (including the autonomous City of Cagayan de Oro) found that turbidity, TDS, chloride, total hardness, and pH were all within the PNSDW's, as well as the USEPA, EU, and WHO's aesthetic standards. This result indicates that the water is of satisfactory quality. On the other hand, the vast majority of the samples failed to meet the total coliform and *E. coli* standards. Some of the samples were chlorinated, but they still failed the microbiological test, which is concerning. Even more concerning is the fact that the microbiologically unfit water was routinely given to consumers. Water from various sources contained permissible levels of heavy metals and other metals.

The western Misamis Oriental groundwater samples were determined to be in compliance with PNSDW and USEPA regulations, with the exception of a few sites, mainly in the municipalities of Initao, Gitagum, and Libertad. TDS levels in groundwater samples from Initao and Gitagum are well above the acceptable levels. Groundwater in Initao, Gitagum, and Libertad contains high levels of cholrides. Libertad's groundwater was also found to have a high total hardness. Samples from all seven locations in western Misamis Oriental failed the total coliform test, while

E. coli was found in samples from the municipalities of Laguindigan, Lugait, Gitagum, and Libertad (Leopoldo et al., 2017).

The upland and coastal freshwater from spring sources in Misamis Oriental meets the physico-chemical standards of the Philippines, the United States of America, the European Union, and the World Health Organization. However, upland freshwaters are better than coastal freshwaters in terms of conductivity, TDS, salinity, chlorides, and TOC. Favorable findings have been observed for heavy metals that pass the various standards, with the exception of antimony, which is rather doubtful when compared to the stricter USA and EU requirements. Microbiological tests found significant fecal bacteria pollution in both upland and coastal freshwater sources (Besagas et al., 2015).

In 2015, water samples from the Santa Rosa River revealed BOD levels ranging from 13 to 52 mg/L, indicating that the river is already moderately to very polluted in comparison to desired water quality (class B). According to the study's future scenario, water quality will decline substantially by 2030 in all scenarios. Population expansion was found to have the greatest impact on future water quality deterioration, while climate change had the least (but not insignificant) impact (Kumar et al., 2020).

A study of the effects of climate change on the Mount Makiling forest watershed indicated that extreme changes in hydrologic events result in large evaporation losses and streamflow decreases. However, it appeared as though the ground water flow remained undisturbed (Combalicer et al., 2010).

In terms of water governance, a study discovered that the numerous legal documents governing water are confusing; that water data for planning is insufficient; that there are numerous water agencies that are not connected vertically or horizontally; and that these various institutions lack the necessary human and financial resources and local presence to carry out their mandates effectively. That is why it was proposed that 1) the legislative and institutional framework for water be reviewed; 2) planning and decision-making mandates be strengthened; and 3) more participatory models of water governance tailored to the Philippine setting be studied and implemented (Rola et al., 2015).

Conclusion

The provision of safe drinking water remains a complex challenge that requires balancing immediate biological safety with long-term chemical security. While water treatment and disinfection are non-negotiable interventions for preventing waterborne diseases such as cholera and typhoid, this review highlights a critical paradox in public health engineering. The very process used to render water microbiologically safe—chlorination—introduces a new spectrum of health risks through the formation of Disinfection By-products (DBPs). Chlorine is widely used due to its cost-effectiveness and efficacy, yet its reaction with natural organic matter inevitably generates Trihalomethanes (THMs), which are proven to be carcinogenic, teratogenic, and genotoxic. Therefore, a holistic approach to water safety must ensure that supplies are devoid not only of biological contaminants but also of these dangerous chemical by-products.

Despite the existence of rigorous standards set by the World Health Organization (WHO) and the Philippine National Standards for Drinking Water (PNSDW), there is a disconnect between policy and practice regarding chemical safety. This review identifies a glaring void in the scientific literature: there are currently no available studies documenting THM levels in Philippine drinking water. In the specific case of the Cagayan de Oro Water District (COWD), no research-gathered information exists regarding these contaminants. This lack of data is largely attributed to logistical barriers, as THM parameters and THM Formation Potential (THMFP) are routinely excluded from water quality monitoring due to the high cost and unavailability of necessary reagents.

Water Quality Addressing this research gap is urgent. Studies projecting future water scenarios indicate that water quality is likely to decline substantially by 2030, driven primarily by population expansion and anthropogenic waste. As raw water sources become more polluted with organic matter from agricultural and industrial runoff, the potential for DBP formation during chlorination increases. Without establishing a baseline for THM levels now, regulatory bodies cannot effectively manage the rising cancer and health risks associated with long-term exposure.

Finally, water safety is not solely a technical issue but also a social one. Public acceptance and awareness are pivotal for the success of pollution prevention and health protection. This review underscores the importance of educating consumers, as informed individuals can take practical measures to protect themselves. For instance, simple household interventions like boiling tap water can reduce THM volatility by 61–82%, significantly lowering exposure. Consequently, future strategies must combine rigorous scientific monitoring of DBPs with aggressive public education campaigns to ensure a water supply that is truly safe for the Filipino population.

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